On the Polarisation of X-Rays compared with their Power of exciting High Velocity Cathode Rays.

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(Communicated by Prof. W. H. Bragg, F.R.S. Received December 8, 1909,—Read January 13, 1910.)

Introduction.

1. The discovery of polarisation of Röntgen rays* was suggested by the ether pulse theory, and gave this theory a good support. But, on the other hand, the theory meets with many difficulties when we are going to account for a number of other properties of these rays which recent investigation has brought to light.

Sir J. J. Thomson has tried to make the ether pulse theory consistent with observations by introducing new properties for the pulse-medium, and assumes that the ether has a structure, and that the energy radiating from the pulse centre is transmitted along "lines of force" with undiminished intensity. Prof. W. H. Bragg has assumed, in the so-called "neutral pair theory," that the rays are of a corpuscular nature. For a fuller discussion of the arguments in favour of this view I must refer to Prof. Bragg's papers.† I shall here confine myself to mentioning that one of the chief difficulties on the ether pulse theory is to explain the properties of secondary cathode rays, as the latter, on account of the relation existing between their velocity and the hardness of the bulb,‡ must be supposed to get their energy from the exciting X-rays. What may be said to offer some difficulty to the neutral pair theory is the existence of polarisation, and although Bragg has called attention to the fact that the neutral pairs possess all properties which are necessary to produce asymmetric phenomena of the kind termed polarisation, there still remains some difficulty in explaining that the polarisation is able to make itself felt already in the primary beam, and to explain why certain directions of spin of the doublet should be more likely to occur than others.

We know that the rays that start from the anti-cathode are of a somewhat complex nature, and the possibility suggests itself that the primary X-rays might consist of two kinds of rays, one kind showing polarisation superposed on another kind possessing the property of emitting secondary cathode rays of high velocity.

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* C. G. Barkla, 'Phil. Trans.' (A), vol. 204, pp. 467—479, 1905; C. G. Barkla, 'Roy. Soc. Proc.' (A), vol. 77, p. 247, 1906.

† W. H. Bragg, 'Phil. Mag.,' vol. 14, p. 429, 1907; W. H. Bragg and Madsen, 'Phil. Mag.,' vol. 15, p. 663, 1908, and vol. 16, p. 918.

‡ P. D. Innes, 'Roy. Soc. Proc.,' A, vol. 79, p. 442, 1907.

It was mainly to make clear this point that I was led, after the suggestion of Prof. Bragg, to undertake the following investigation on polarisation of primary X-rays. At the same time the experiments will have interest for the question as to the existence of polarisation in the primary beam, because different observers do not agree on this point. Measurements made by the ionisation method* have given positive results. Haga,† using the photographic method, came to the conclusion that no polarisation of the primary beam existed, while Herweg,‡ by the same method, got a positive result.

In the following experiments an ionisation method has been adopted; the greatest care, however, has been taken to eliminate the effect of possible variation in the intensity across the primary incident beam and of excentric incidence on the secondary radiator.

In addition, some measurements have been made to find the relation between the polarisation and the angle of incidence of the cathode rays on the anti-cathode.

Apparatus.

2. The arrangement for analysing the primary beam for polarisation, which forms the most important part of the apparatus, is shown in figs. 1 and 2, giving the parts A and B (fig. 3) on a larger scale. B (figs. 1 and 3) is a wooden box covered with lead and introduced in order to increase the distance between the anti-cathode and the secondary radiator. The part A (fig. 1) containing the secondary radiator and the ionisation chambers is made after the design of Prof. Bragg. A and D (fig. 1) are two square boxes made of zinc plates (about 2 mm. thick), one placed outside the other. The horizontal section of the two boxes forms squares, having the same centre and their sides parallel (see fig. 2).

The secondary radiator (R, fig. 1) had the form of a cylinder with a conical top, and consisted of paraffin wax. This substance was chosen, as it is found to be very effective in showing polarisation.§ The radiator was fixed to the inner box in the way indicated in fig. 1, with its axis vertical and coinciding with that of the two boxes A and D.

The secondary radiation was cut off by the inner box (D), except at four circular apertures symmetrically arranged on the four side walls of the box. The intensities of the four beams passing through these openings were measured by the ionisation in four equal and symmetrically arranged ionisation chambers (1, 2, 3, 4), fig. 2, each consisting of two circular parallel plates *a* and *b*.

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* C. G. Barkla, *loc. cit.*; E. Bassler, 'Ann. d. Phys.,' vol. 28, p. 808, 1909.

† H. Haga, 'Ann. d. Phys.,' vol. 28, p. 439.

‡ J. Herweg, 'Ann. d. Phys.,' vol. 29, p. 398, 1909.

§ E. Bassler, *loc. cit.*

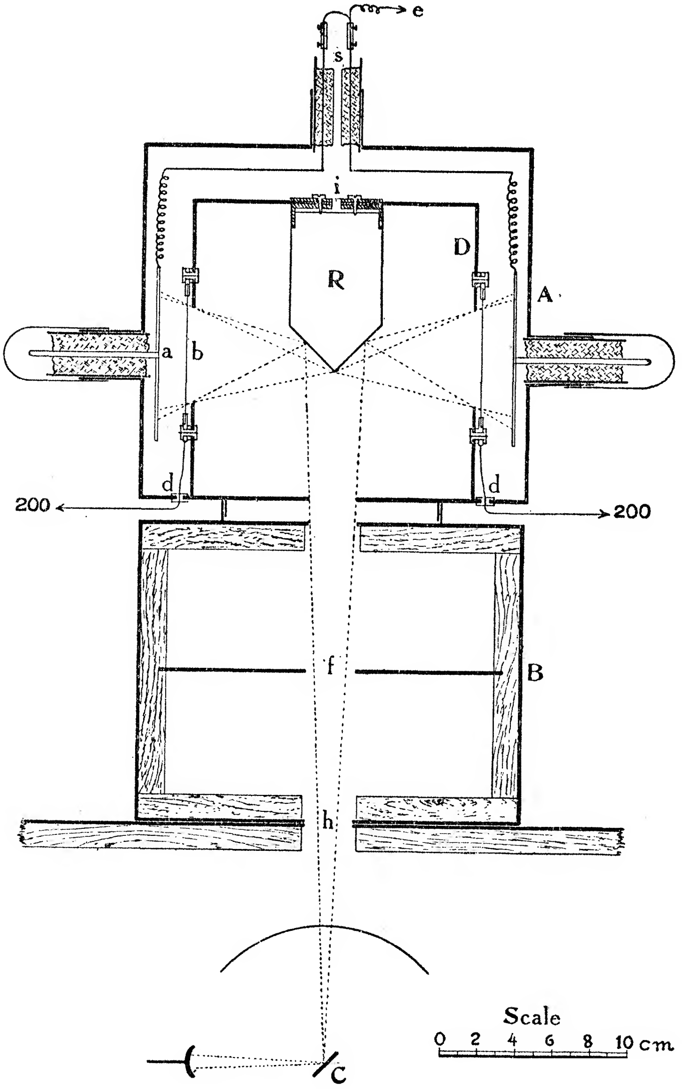

Fig. 1.

The outer plate, made of aluminium (1·5 mm. thick), was supported by a brass rod fixed in a brass tube by a plug of sulphur. This brass tube was made to fit exactly inside another brass tube fixed to the outer box. These plates were connected to four wires, all of which went through the same sulphur plug (*s*) on the top of the outer box, and in such a way as to be insulated from each other as well as from the box. By this arrangement the wire (*c*) leading to the electroscope could easily be connected to the ionisation chambers in any combination wanted.

The inner plates, which we shall call the windows, were fixed to and insulated from the inner box by means of plugs of ebonite (*c*), and given potentials sufficient for saturation. In my experiments two different kinds of windows were used, which will be referred to as W_1 and W_2. The windows W_1 were made of very thin paper, coated on one side with one layer of gold leaf, on the other with one layer of aluminium foil. The windows W_2 were made of thin sheets of aluminium covered on one side with three layers of gold leaf.

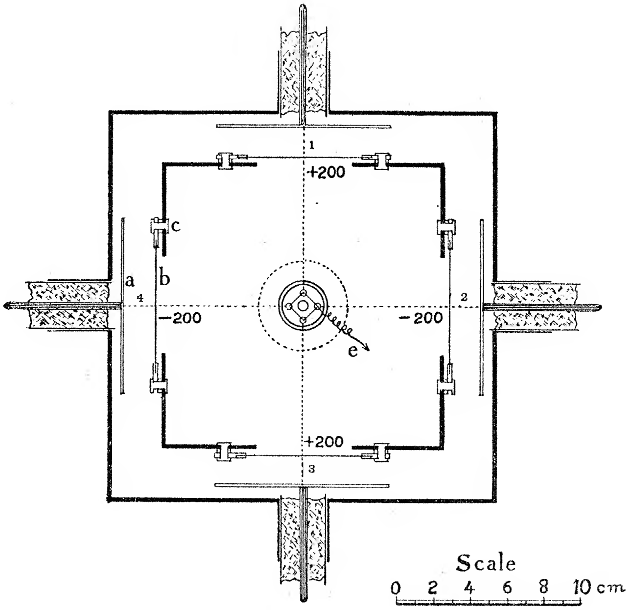

Fig. 2.

The inner box was screwed on to the bottom plate, the outer one (A) could be taken off. To be sure that (A) always kept the same position, it rested on three short conical feet that fitted into corresponding borings in the bottom plate.

Underneath the bottom plate of the box (A, fig. 3) was fixed a short brass cylinder exactly fitting into another short brass cylinder fixed on the top of the box B. This enabled the whole top box with the secondary radiator and the four ionisation chambers to be turned round a vertical axis coinciding with that of the primary beam. Moreover, the paraffin cone could be separately turned round the same axis, and this could be done, without removing the outer box (A), by means of a brass rod put into the square hole (*i*) through the aperture in the sulphur plug (*s*).

The primary rays that struck the radiator had to pass through a series of circular apertures (fig. 1) with their centres on the axis of the radiator. The diameter of the apertures was 2·4 cm. The distance from the top of the cone to the anti-cathode was about 40 cm. In this way the solid angle (w) of the ray bundle was very small ($w = 2{\cdot}8 \,.\, 10^{-3}$), and the beam only hit the central part of the cone.

As the secondary radiator was long enough to absorb the primary beam, all secondary radiation came from the paraffin.

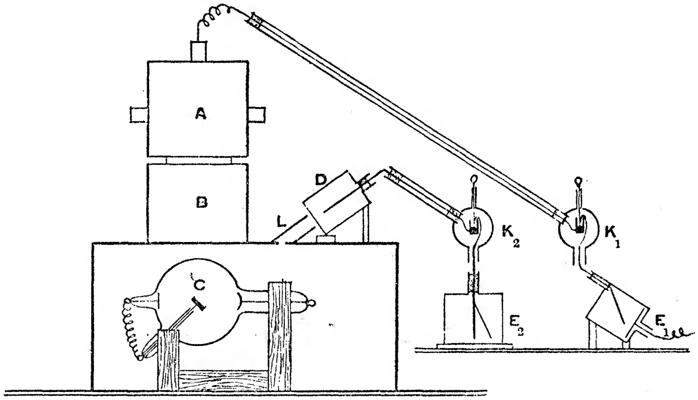

FIG. 3.

A general plan for the arrangements is shown in fig. 3. The bulb (C) was fixed to a wooden frame and put inside a big box covered with lead. The cathode ray beam had always a horizontal direction. The bright spot on the anti-cathode that formed the main source of primary X-rays was brought to coincide with the axis of the radiator in the following simple way:—A small mirror on the top of the middle plate of the box B was put in such a position that the anti-cathode could be seen through the openings *h* and *f*, and the spot on it brought into central position.

E_1 is an electroscope of the Wilson type used for measuring the secondary radiation. The sensitiveness of this instrument was not the same at different parts of the scale. This difficulty was overcome by keeping the microscope and the electroscope in an unchanged position. In this way the sensitiveness at the various points of the scale kept nearly constant. In fact the sensibility curve was generally the same during a whole day, and underwent only small changes during the whole course of my experiments.

D (fig. 3) is a standardising chamber connected to an electroscope E_2. The primary beam went through a narrow aperture in the lead box, then through a short lead tube L, and entered the chamber through a thin paper wall coated with aluminium foil. K_1 and K_2 are keys for earthing the gold leaves.

The lead boxes, the two zinc boxes (A) and (D), fig. 1, and the brass tubes surrounding the connection wires were all put to the same earth. Every care was taken to make the apparatus accurate and symmetrical.

Mode of Procedure.

3. To measure the polarisation a zero-method was adopted. The windows of the two opposite chambers (1, 2) were charged to + 200 volts, the two others to − 200 volts. During the determination of polarisation the bulb was kept unaltered, while the box A containing the chambers was turned.

For each determination of the polarisation the following observations were taken :—

Position I.—Line combining the centres of the positive chambers perpendicular to the cathode rays.

(1) The two positive chambers were connected to the electroscope E_1, and the ionisation V_p' measured.

(2) All four chambers were connected and the leak α' measured.

Position II.—Box A turned 90°.

(3) All four chambers connected and the leak α'' measured.

(4) The two negative chambers were connected and the leak V_n'' measured.

The observations were made as follows :—

The coil was made to run until a suitable deflection was obtained in the electroscope E_1. When the leak in the two opposite chambers was measured, the rate of motion of the gold leaves in E_1 and E_2 was of the same order. The rate in E_1 varied in different experiments, but was of the order of 20 to 30 divisions per minute, the rate in E_2 generally somewhat larger.

When all four chambers were connected, however, the motion of the leaf in E_1 was very slow compared with that of E_2, and even letting the leaf in E_2 traverse the whole scale, the corresponding deflection in E_1 was too small for an accurate determination. In this case several deflections in E_2 were added to make up a suitable deflection (5 to 10 divisions) in E_1. In general two or three such portions were sufficient, and thus in order to get one determination of the polarisation the coil had to be run altogether about five minutes.

The scale value was determined in the usual way by charging the leaf to a series of known potentials, and from this the scale value for different parts of the scale could be found. For E_2 the scale value was very nearly constant all over the scale, but for E_1 it varied considerably; but as already mentioned, the sensibility curve kept very nearly unchanged, and it was found sufficient to determine it twice a day before and after the observations.

The sensitiveness of E_2 was about 1 div. per volt.

The maximum sensitiveness of E_1 was about 15 div. per volt.

The natural leak was examined repeatedly, but was too small to have an appreciable effect on the observations.

To determine the efficiency of the polarised rays in producing high velocity cathode rays, the windows were turned and the same series of observations repeated with the windows in the new position.

On the Treatment of the Observations.

4. The polarisation will be defined by the following expression:—

$$P = \frac{I_M - I_m}{I_M + I_m}; \tag{1}$$

I_M and I_m are intensities of secondary radiation in a plane perpendicular to the axis of the primary X-ray bundle; I_M is measured in direction perpendicular to I_m parallel to the direction of the cathode ray beam.

We shall first treat the case, that the intensity of the secondary X-radiation traversing the same chamber is supposed to be proportional to the ionisation produced in this chamber, the relative position between the source and the chamber being the same.

We get the following equations:—

$$\left.\begin{aligned} I_M = \frac{C_1 V_p'}{K_p}, \quad I_m = \frac{C_1 V_n'}{K_n} \qquad &(2a) \\ C_1(V_p' - V_n') = C_0 \alpha' \qquad &(2b) \end{aligned}\right\} \text{Position I.}$$

$$\left.\begin{aligned} I_M = \frac{C_1 V_p''}{K_p}, \quad I_m = \frac{C_1 V_n''}{K_n} \qquad &(3a) \\ C_1(V_p'' - V_n'') = C_0 \alpha'' \qquad &(3b) \end{aligned}\right\} \text{Position II.}$$

V_p is the leak observed when E_1 is connected to the two positive chambers.
V_n ,, ,, ,, ,, ,, negative ,,
α ,, ,, ,, ,, all four chambers.

The leaks are measured by the potential to which E_1 is charged when E_2 has received a charge corresponding to 1 volt.

E_1 is the capacity of the system when the electroscope is connected to two opposite chambers, C_0 the capacity when E_1 is connected to all four chambers. K_p and K_n are constants characteristic for the two positive and the two negative chambers respectively.

Forming the expression in equation (1) by means of (2) and (3),

$$P = \frac{C_0}{C_1}\frac{\alpha'-\alpha''}{V_p'+V_n'+V_p''+V_n''}.$$

We see that the quantities K_p and K_n depending on the chambers disappear. Using equations (2*b*) and (3*b*),

$$P = \frac{Q}{1-Q}, \quad \text{where} \quad Q = \tfrac{1}{2}\frac{C_0}{C_1}\frac{\alpha'-\alpha''}{V_p'+V_n''}. \tag{4}$$

Q contains, besides the four quantities observed, a factor C_0/C_1, which is a constant for the instrument.

As the capacity c of the electroscope with connection wires is small compared with that of the chamber C, we get $\frac{C_0}{C_1} = 2\left(1-\frac{c}{4C}\right)$, where $c/4C$ is found to be 0·12, and this gives

$$Q = 0{\cdot}88\frac{\alpha'-\alpha''}{V_p'+V_n''}.$$

This expression (4) for the polarisation will be approximately a correct one in the case that the aluminium sides of the windows are next to the chamber, and the radiation only excites a small amount of cathode rays inside the chambers. In general, when we assume corpuscular radiation to partake in the ionisation the equations will have to be modified.

We shall consider the case that the primary beam is made up of two parts, one portion non-polarised and one partly polarised, and we shall suppose the two parts to have a different power of exciting high velocity cathode rays. Instead of equations (1), (2*a*), and (3*a*) we get

$$P = \frac{p_M-p_m}{2u+p_M+p_m}. \tag{5}$$

$$\left.\begin{aligned} \mu(1+H_1)+p_M(1+H_2) &= \frac{C_1V_p'}{K_p} = \frac{C_1V_n''}{K_n} \\ \mu(1+H_1)+p_m(1+H_2) &= \frac{C_1V_p''}{K_p} = \frac{C_1V_n'}{K_n} \end{aligned}\right\}. \tag{6}$$

The equations (2*b*) and (3*b*) remain the same.

H_1 is a measure for the intensity of cathode radiation produced inside the chamber per unit intensity of the *unpolarised* part of the X-ray beam.

H_2 is the corresponding quantity for the polarised part. Treating these equations (6), (2*b*), and (3*b*) in the same way as before,

$$(1+H_2)(K_p+K_n)(p_M-p_m) = C_0(\alpha'-\alpha''), \tag{7}$$

$$(p_M-p_m)\Big/\left(2\frac{1+H_1}{1+H_2}u+p_M+p_m\right) = \frac{Q}{1-Q} = P'. \tag{8}$$

Q is determined in the same way as before. Comparing (5) and (8), we see that $Q/(1-Q)$ no longer gives the true value for the polarisation except in the case that $H_1 = H_2$.

5. *The effect of turning the windows* consists in the variation of constants appearing in the two equations (7) and (8). In the expressions to the left in these equations it is only H_1 and H_2 that vary; for as the secondary beam has the same matter to traverse in both positions of the windows the quantities μ, p_M, and p_m remain the same.

Further, the quantities K_p and K_n are not affected because they only depend on the volume and shape of the chambers.

Let H_1^a and H_2^a be the constants when aluminium is next to the chamber,
H_1^g „ H_2^g „ „ gold „ „ „

Then we get from (7),

$$\frac{\alpha_g'-\alpha_g''}{\alpha_a'-\alpha_a''} = \frac{1+H_2^g}{1+H_2^a} = 1+\epsilon_2, \quad \text{where} \quad \epsilon_2 = H_2^g - H_2^a. \tag{9}$$

From (9) we see that the necessary and sufficient condition for ϵ_2 to be equal to zero is

$$\alpha_g'-\alpha_g'' = \alpha_a'-\alpha_a''. \tag{10}$$

Equation (10) *expresses the experimental condition to be fulfilled if the polarised beam is unable to produce cathode rays of high velocity.*

If equation (8) is employed for the two positions of the windows,

$$\frac{P_g'}{P_a'} = \left(\frac{1+H_1^a}{1+H_2^a}2\,u+p_M+p_m\right)\Big/\left(\frac{1+H_1^g}{1+H_2^g}2\,u+p_M+p_m\right). \tag{11}$$

The equation $P_a' = P_g' = P$

expresses the experimental condition to be fulfilled in order that the two parts of the beam shall have the same power of exciting high velocity cathode rays.

When the polarised part of the beam is very small compared with the unpolarised and Pg' is not very different from Pa', as will be the actual case, we get very approximately from (11),

$$\frac{P_g'}{P_a'} = \frac{\epsilon_2}{\epsilon_1}, \quad \text{where} \quad \epsilon_1 = H_1^g - H_1^a. \tag{12}$$

H_1^a and H_2^a being very small, we see that ϵ_1 and ϵ_2 give respectively a measure for the efficiency of the unpolarised and the polarised part of the radiation in producing high velocity cathode rays, and their values can be found in a very simple way from (9) and (12).

Possible Errors.

6. (1) Differences in the ionisation due to differences in the four chambers are compensated for by turning the chambers through 90°.

(2) To be sure that the measured polarisation was wholly due to properties in the primary beam, the bulb was turned round a vertical axis through an angle of 90°. The polarisation was measured and found to be exactly the same in the new position of the bulb.

(3) Possible asymmetry in the secondary radiation due to differences in the paraffin cone was tested by turning the cone while the chambers were kept in their position, but the rotation of the cone caused in fact no change in the ionisation.

(4) Another error might be caused by excentric incidence of the primary beam on the paraffin cone. This was corrected for by having four chambers, so the simultaneous ionisation in two opposite chambers gives the mean intensity in the two opposite directions.

(5) The most serious difficulty in applying corrections arises from the possibility that the primary beam may vary in intensity across the beam. Taking the average effect over a considerable time, we must be able to assume that the intensity across the beam varies in a continuous way. In a plane perpendicular to the ray bundle the intensity can be expressed by $I = \phi(x, y)$, where x and y are rectangular co-ordinates in the plane, and if the centre of the cross-section is taken as origin,

$$I - I_0 = \left(\frac{\partial I}{\partial x}\right)_0 x + \left(\frac{\partial I}{\partial y}\right)_0 y +, \text{ etc.}$$

If we exclude the singular case that $(\partial I/\partial x)_0$ and $(\partial I/\partial y)_0$ both vanish, the variation will act in a similar way as an excentric incidence, and is compensated for in the same way by measuring the mean intensity in opposite directions from the secondary radiator.

The case that $(\partial I/\partial x)_0$ and $(\partial I/\partial y)_0$ both vanish and the quantities $(\partial^2 I/\partial x^2)_0$, $(\partial^2 I/\partial x\,\partial y)_0$, and $(\partial^2 I/\partial y^2)_0$ have finite values need to be considered, because a ray bundle with intensity varying in this singular way would produce a distribution of secondary radiation of the same kind as in the case of polarisation.

Such a singular point, however, is not likely to occur. It could only exist along a certain cone through the source or along a finite number of ray directions, but, as shown by Barkla and Bassler, the primary rays are found to be polarised in directions of the primary radiation lying within wide limits. Another important argument for not supposing such a singular point to occur is, that when the light substances are replaced by heavy metals as secondary radiators no polarisation is found. The variation of the polarisation with the angle of incidence of the cathode rays also shows the impossibility of explaining polarisation from variation in intensity across the primary beam.

(6) Irregularities in the running of the bulb were compensated for by the standardising chamber E_2. It was found that the ratio between the ionisation in E_1 and E_2 kept constant during long intervals of time, but only as long as the position of the bulb was kept unaltered, and, as we have seen, the polarisation could be measured without moving the bulb. To correct for gradual changes in the state of the bulb, a greater number of measurements were taken in series in such a way that the windows were alternately turned, and by these means the observations for the two positions of the windows could be reduced to the same state of the bulb.

Results.

7. Tables I and II give the results of measurements with the window W_1 and W_2 respectively. The values inside each horizontal column are the mean of a considerable number of observations taken quickly in succession in the way described. We see that in all cases $\alpha_g'-\alpha_g''$ is considerably greater than $\alpha_a'-\alpha_a''$. In view of equation (10) this shows that *the polarised part of the beam has a considerable power of exciting high velocity cathode rays.*

We further see that P_g' is somewhat larger than P_a', and ϵ_2 in our experiments is always greater than ϵ_1; in other words, *the polarised part of the beam has on the average a greater power of producing high velocity cathode rays than the unpolarised part.*

Table I.—Window W_1.

	$V_p'+V_n''$.	$\alpha'-\alpha''$.	P_a'.	P_g'.	ϵ_2.	ϵ_1.	ϵ_2/ϵ_1.
Alum. ……	0·0683	0·00561	0·0782	—	0·87	0·74	1·18
Gold ……	0·1100	0·0105	—	0·0920			
Alum. ……	0·0687	0·00523	0·0719	—	0·97	0·79	1·22
Gold ……	0·1134	0·0103	—	0·0882			
Alum. ……	0·0711	0·00448	0·0590	—	0·83	0·75	1·11
Gold ……	0·118	0·00818	—	0·0655			

Table II.—Window W_2.

	$V_p' + V_n''$.	$a' - a''$.	P_a'.	P_g'.	ϵ_2.	ϵ_1.	ϵ_2/ϵ_1.
Alum.	0·0680	0·00449	0·0619	—	0·98	0·83	1·18
Gold	0·116	0·00890	—	0·0730			
Alum.	0·0698	0·00375	0·0497	—	1·14	0·98	1·17
Gold	0·128	0·00805	—	0·0584			
Alum.	0·0720	0·00310	0·0406	—	0·94	0·87	1·08
Gold	0·126	0·00600	—	0·0439			

The ratio ϵ_2/ϵ_1 varies in such a way that it is greater for a greater absolute value of the polarisation. As the polarisation increases with the softness we may say that ϵ_2/ϵ_1 increases with the softness of the bulb.

Comparing the values for ϵ_1 and ϵ_2 in the two tables, we see that increasing the thickness of gold from one to three layers of foil only very slightly increases the relative amount of ionisation due to corpuscular radiation. The somewhat larger values for ϵ_2 and ϵ_1 in the middle column in Table II is most probably due to the fact that they were the first observations taken with the new window, and the fresh gold surface gives a somewhat larger cathode radiation.

Table III shows the effect of screening the primary beam before it strikes the secondary radiator. The screen consisted of a number of aluminium plates that cut off the intensity to about the half of its value.

Table III.

	$V_p' + V_n''$.	$a' - a''$.	P′.	ϵ_2.	ϵ_1.	ϵ_2/ϵ_1.	
Gold	0·0731	0·00411	0·0520	0·93	0·91	1·02	With screen.
Alum.	0·0387	0·00213	0·0510				
Gold	0·126	0·00600	0·0439	0·936	0·85	1·08	Without screen.
Alum.	0·0702	0·00310	0·0406				

The effect is, shortly, the following:—

(1) The polarisation is increased by the screen.

(2) The power of the polarised part of the beam to produce cathode rays appears to be nearly unchanged after passing through the screen, while

(3) The efficiency of the unpolarised part in producing cathode rays is increased, so ϵ_2 and ϵ_1 become very nearly equal.

It seems from this *that the polarised part is a more penetrating and homo-*

geneous type of radiation than the unpolarised, which is more changed in properties by the screen.

Relation between Polarisation and Angle of Incidence of the Cathode Rays.

8. The bulb used for this investigation differed from an ordinary Röntgen bulb in that the anti-cathode was fixed to a short glass tube, which was ground to fit into another one in such a way as to enable the anti-cathode to be turned round an axis nearly horizontal and perpendicular to the cathode rays.

The bulb was put into the big lead box, and in a similar position as for the previous experiments. It was evacuated by a Gaede pump, and connected to it through a glass tube, which could be closed by a glass tap.

To get the bulb into a steady state, it had to be run with the coil and repumped a great many times and for various positions of the anti-cathode. The last precaution was necessary, because the turning of the anti-cathode caused new parts of it to be struck by the cathode rays.

The bulb was kept exactly in the same position during the whole series of measurements. The results are shown in Table IV. The numbers in the vertical columns correspond to series of determinations taken in rapid succession, and in the order in which they are put in the table.

Table IV.

ϕ.	P.	ϕ.	P.	ϕ.	P.
12°	0·077	70°	0·119	66°	0·102
40°	0·082	45°	0·103	55°	0·098
56°	0·085	32°	0·105	38°	0·084
		6°	0·094	7°	0·076
				32°	0·083

ϕ is the angle between the cathode rays and the normal to the anti-cathode.

We see that the values of the polarisation in each vertical column, which should be comparable, show very small differences, which, however, occur in a regular way, especially so that the polarisation shows a slight decrease when ϕ is diminished.

This experiment shows definitely that the polarisation cannot be due to any singular distribution of intensity across the primary beam. The origin of such a distribution must either be sought in an uneven thickness of the glass of the bulb or in the distribution of intensity in the source. That the first is not the case is shown by the fact that further screening increased the polarisation. In the last experiment the shape of the source has been altered while everything else has remained the same. When ϕ is very small, the source seen from the radiator is nearly of the shape of a short straight line *perpendicular* to the cathode rays; but for oblique incidence the source seen in the same direction is widest *parallel* to the cathode rays. Thus the effect of an uneven distribution caused by the source should be opposite for a small and for a large value of ϕ, and should act in the same direction as the polarisation when ϕ is small. The results show that the polarisation is very nearly independent of the shape of the source; even the small variation found in the polarisation cannot be due to variation in intensity distribution, because the effect found is opposite to that to be expected from variations in the source.

The variation found must be due to a change in the polarisation. The only possible variations in the conditions for the formation of X-rays caused by a change in ϕ seems to be the following four:—

(1) By turning the anti-cathode the spot of incidence may shift about and this may change the amount of gas given out relative to that absorbed and thus cause an irregularity in the variation of the state of the bulb. As already stated, this effect was reduced by running the bulb for various positions of the anti-cathode before the measurements were taken. Further, a change caused in this way ought to be quite irregular and irreversible. But we see from the table that the variation occurs in a regular way and does not depend on the order of operation, so the variation of the polarisation must be sought in the variation of some other condition.

(2) By oblique incidence the same amount of cathode rays strike a larger surface than when ϕ is small, and it might be possible that the contraction of the spot of incidence might diminish the polarisation.

(3) The effect of a contraction of the spot of incidence might be a secondary one, due to changes in temperature in the spot, and if this was the cause of the change in P the observation would show that the polarisation was diminished by increase of temperature.

(4) The relative amount of X-radiation coming from the surface layer will increase with the angle of incidence, and it is quite possible that the more X-radiation there is formed in the surface layer the greater will be the polarisation.

To decide how far the three last conditions may account for the observed variation would require further experimental knowledge regarding the formation and properties of X-radiation.

The way in which the polarisation has been expressed in this paper is practically the same as that used by Bassler. Barkla, however, expresses his results differently, in fact he has used two different ways* of calculating the polarisation: one makes the numbers twice, the other makes them four times as large as if calculated after the method here adopted. Thus the highest value found by Barkla for polarisation of the primary beam calculated in our way is about 0·05. The highest number appearing in the tables is 0·12, but even still higher values have been obtained. The second bulb, in a very soft state and with an anti-cathode of Ni, gave a polarisation of 0·27 in the primary beam. In this connection it is of interest to notice that the polarisation in the secondary beam as found by Barkla calculated in the way here used is about 0·52.

Summary.

1. The existence of polarisation in the primary radiation is confirmed by a method which efficiently compensates for possible errors.

2. The part which is polarised possesses at the same time a great power of exciting high velocity cathode rays, which shows that the polarised and unpolarised part in this respect are essentially of the same type.

3. The efficiency of producing high velocity cathode rays is even somewhat greater for the polarised than for the unpolarised part of the beam, and the difference between ϵ_2 and ϵ_1 increases with the softness of the bulb.

4. Screening the beam before striking the radiator slightly increased the polarisation. It had no observable effect on the efficiency of the polarised part to produce cathode rays, while that of the unpolarised was increased, so ϵ_1 became nearly equal to ϵ_2.

5. The angle of incidence of the cathode rays, when other conditions were the same, had a very small but still noticeable effect on the polarisation, the latter being greater for a greater angle. This experiment shows conclusively that the polarisation cannot be accounted for by any singular distribution of intensity across the primary beam.

In conclusion, I wish to thank Professor W. H. Bragg for suggesting to me the subject of the research, which was carried out in the University of Leeds, and for the kind interest he has taken in its progress.

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* 'Phil. Trans.' (A), vol. 204, compare p. 474 and p. 479.